A Collaborative VR Visualization Environment for Offshore Engineering Projects

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Abstract

The current way of designing industrial plants relies on the communication among experts in the field, and on tools that allow the simulation of the site. Virtual reality (VR) tools are used to visualize and interact with complex 3D environments in real time, and several engineering simulations employ VR to foresee the results of complex industrial operations. The research project described here presents a collaborative engineering environment (CEE) that integrates VR techniques into a system where the execution of different sequences of engineering simulations is modeled as scientific workflows. The focus of this research is on the oil & gas industry, particularly offshore engineering, where the project of a new production unit is a lengthy and expensive process and usually is conducted by different specialists who are geographically distributed. Among the integrated engineering simulations are those involving structural calculus, hydrodynamics, naval engineering with mooring systems, meteo-oceanography, and others. The main objective is to improve the users' interpretation capacity and skills while providing visualization tools for a better understanding of the results.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics; Realism– Virtual reality; Graphics systems; Distributed network graphics;

Keywords: three-dimensional graphics; virtual reality; collaborative virtual environments; offshore engineering.

1 Introduction

In recent years, the oil & gas industry has seen increasing costs for finding and lifting hydrocarbons, especially in remote locations, ultra-deep water reservoirs or hostile environments. The development of deep-water oil & gas reserves constantly faces the challenge of trying to reduce the costs of all components and activities. Therefore, high performance computing, visualization and remote collaboration technologies are being extensively used to improve productivity, leading to better cost-effectiveness.

Earth sciences and engineering have to manage and interpret increasing amounts of data captured from the environment or generated by computer simulations. The typical work of scientists and engineers consists in detecting features, measuring them, and finally generating a model that attempts to explain those observed features. This visual approach to science and engineering is powerful, as the human brain excels at identifying patterns visually. As Edward Tufte [1983] wrote more than two decades ago, "At their best, graphics are instruments for reasoning about quantitative information. Often the most effective way to describe, explore and summarize a set of numbers – even a very large set – is to look at pictures of those numbers".

Visualization and remote collaboration technologies help us to bridge the cost-effectiveness problem. In the past years, the industries have achieved sensitive gains in efficiency and effectiveness when carrying out projects using virtual reality technologies. Oil companies were among the first to make industrial use of the so-called virtual reality centers, equipped with immersive projection systems with large display walls and videoconference tools, among other solutions. Three-dimensional geometric modeling, scientific visualization and immersive virtual environments, commonly used in these facilities, pushed the limits of teamwork activities in geosciences and engineering.

When used in conjunction with collaboration, VR visualization provides valuable insights for better decision support with risk mitigation. Dodd [2004] has mentioned that the next big management push is the empowerment of interdisciplinary teams with collaboration tools that include remote and immersive visualization on the desktop. With this in mind, we emphasize that the combination of collaborative tools and VR visualization constitutes a powerful asset in any software solution for large scale engineering projects.

The present work is motivated by the necessity of developing effective solutions for collaboration among team members during the execution of large and complex offshore engineering projects. Such projects usually require the execution of a number of engineering simulations, encapsulated as engineering services. These are combined in different orders and rearranged in different subsets according to project requirements, comprising different scientific workflows [Deelman et al. 2009] especially tailored for the offshore engineering field.

By means of a scientific workflow management system (ScWfMS), users are able to orchestrate the execution of engineering simulations as workflow tasks that can be arranged in many different ways. Within a workflow, as its last step, the most interesting cases can also be selected for visualization in an immersive collaborative session. A simplified grid computing infrastructure seamlessly integrated into the system supports the distributed execution of simulations. Collaboration support is provided by a videoconference system [Pozzer et al. 2003], a mechanism for creating private and shared 3D annotations connected to engineering artifacts, and additional visualization feed-through mechanisms that improve system awareness. Those features compose a collaborative problem-solving environment that enables engineers to set up computations in an integrated environment [Houstis et al. 1997]. The CEE is therefore composed of the following tools for distributed group work:

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1. ***Virtual reality visualization tool*** for collaborative visualization of simulations in an immersive or desktop environment;
2. ***Scientific workflow management system*** based on BPEL (Business Process Execution Language) [OASIS] workflows, used as a process-oriented tool to control simulations;
3. ***Videoconference system*** developed to support human communication, providing integrated audio and video channels, subject to defined control policies.

In the following sections we present some aspects of the developed system. In section 2 we outline the main characteristics of offshore engineering projects, discussing some of the problems addressed. Related works that inspired the development of the system are presented in section 3. In section 4, we describe the main architecture of the CEE. Some application scenarios are presented in section 5, and conclusions in section 6 finish the paper.

2 Offshore Engineering Projects

In the offshore engineering field, the project of deep-water production systems, including oil platforms or ships and all equipment that plays a part in the production process, is currently designed by means of complex computer modeling systems. The design of a new production unit is a lengthy and expensive process, which can last many years and consume hundreds of millions of dollars, depending on the complexity of the unit and the maturity of the technology required to make the project technically and economically feasible.

Offshore engineering projects involve not only geographically distributed teams but also teams of specialists in different areas using different software tools, both commercial and internally developed. While the interoperability of those tools is still an issue, it is a mandatory requirement for any collaborative solution.

Due to their huge complexity, offshore engineering projects are divided into smaller interrelated subprojects, each one dealing with an abstract representation of the others. Because decisions are interdependent, collaboration is a key issue in this area. Each team activity or decision can affect others. For example, during the design of an oil platform, changing the position of large and heavy equipment in the process plant can compromise the stability of the production unit. In some cases there is also an intrinsic coupling among the solutions of the different subprojects, which requires intensive interaction and discussion among the teams involved. This is the case of the mooring system and of the production riser subsystems. On the one hand, if the mooring system allows the production unit to experience high fluctuations, this can damage the production risers; on the other hand, the mere presence of risers helps to reduce the movements of the production unit, contributing positively to the equilibrium of the system. In order to achieve collaboration and interoperability between those subprojects, a software-based interface is required.

A different problem, related to the need to represent multiple data, is that although specialists deal with the same information (platforms, risers, mooring systems, etc.) they usually have different data representations for those objects according to the needs of each activity. This requires support for multi-resolution representation of the data. For example, in structural and naval engineering the models usually have dense polygonal meshes, with a few objects representing the outline of the artifacts, suitable for numerical analyses of static and dynamic stability studies. The need for different data representation imposes one of two alternatives: either support for multi-resolution representation is implemented, or rendering performance is improved in order to deal with data.

Another challenge posed by offshore engineering projects is related to the visualization of large engineering simulations. During the conceptual design phase of an industrial plant, several simulations must be carried out to assess the robustness and feasibility of the project. Some of these simulations may require huge computational effort to be processed, such as through the use of computer clusters [Soares et al. 2002]. Visualization should be as precise as possible in order to provide the user a full understanding of the results.

CAD/CAE models usually have objects with coarse grid meshes suitable for good visual representation, but the problem is that all the objects that comprise the artifact are represented, yielding huge models. Another aspect is that CAD/CAE models are the best representatives for real artifacts, so there is a tendency to use those models directly in simulations and visualizations. Even today, realistic real-time visualization of those models is a very complex problem in computer graphics [Raposo et al. 2006].

This research project focuses on the development and integration of scientific and visualization tools and technologies coupled with collaborative environments that support the modeling and simulation of complex engineering projects. CEE is designed to solve simple or complex problems, providing support for both rapid prototyping and detailed analysis. The CEE was conceived as a useful solution to control and execute specialized engineering projects by means of its collaboration and visualization capabilities.

3 Related Work

In this section we present a few relevant works that motivated this research towards the construction of a collaborative immersive visualization environment for visualizing engineering simulations.

Parker et al. [1998] describe SCIRun, a problem-solving environment (PSE) that allows users to interactively compose, execute, and control a large-scale computer simulation by visually "steering" a dataflow network model. SCIRun supports parallel computing and output visualization.

Paraview [2011] is a kind of PSE for visualization that allows the interactive creation and manipulation of complex visualizations. Paraview is based on the notion of dataflow, and provides visual interfaces to produce visualizations by assembling pipelines out of modules that are connected in a network.

However, both SCIRun and Paraview have significant limitations. First, there is no separation between the definition of a dataflow and its instances. In order to execute a given dataflow with different parameters, users need to set these parameters manually through a GUI — not scaling to more than a few visualizations. Second, modifications to parameters or to the definition of a dataflow are destructive. Despite their limitations, SCIRun and Paraview show the importance of combining visualization with PSEs.

Paventhan et al. [2006] proposed the creation of WindTunnel, a scientific workflow for wind tunnel applications. They observed that scientific and engineering experiments often produce large volumes of data that ideally should be processed and visualized in near real time. The difficulty to achieve this goal is that the overall turnaround time from data acquisition, transference to a data processor, and visualization of the results is frequently hindered by factors such as manual data movement, system interoperability issues, manual resource discovery for job scheduling, and disparate physical locality between the experiment and the user workstation. The authors argue that customized application-specific workflows could reduce the time taken to accomplish a job by automating dataflow-driven activities, supplementing or replacing manual user-driven tasks. WindTunnel provides a series of workflow activities that allow users to compose sequential workflows and seamlessly access grid services.

Vistrails [Callahan et al., 2006] is a visualization management system that provides a scientific workflow infrastructure, which can be combined with existing visualization systems and libraries. A key feature that sets Vistrails apart from previous visualization systems is support to data exploration. It separates the notion of dataflow specification from its instances. A dataflow instance consists of a sequence of operations used to generate a specific visualization. The approach adopted in Vistrails inspired the strategy behind the software we have developed. Among some of the differences in our solution is the use of a BPEL (Business Process Execution Language) in the ScWfMS [EclipseBPEL].

In the geology field, Kreylos et al. [2006] presented an approach for turning immersive visualization software into a scientific tool. They created an immersive visualization software with measurement and analysis tools that allow scientists to use their real-word skills and methods inside a VE. They emphasize that VR visualization alone is not enough to enable an effective work environment. This observation has also motivated the creation of some additional tools for the VR visualization subsystem proposed here.

In the upstream segment of the oil & gas industry, the determination of optimal well locations is a challenging problem for reservoir engineers [Klie et al., 2004]. Gruchalla et al. [2004] investigated the benefits of immersive VR for well-path editing. They reported higher speed and accuracy in immersive systems than in a desktop system, based on a study with 16 participants who planned the paths of four oil wells. Each participant planned two well paths on a desktop workstation with a stereoscopic display, and two well paths in a CAVE-like immersive virtual environment [Cruz-Neira et al., 2002]. Fifteen of the participants completed the well-path editing tasks faster in the CAVE environment than in the desktop environment. The higher speed was accompanied by a statistically significant increase in correct solutions.

The Fraunhofer Gesellschaft VRGeo Consortium [2011] is an oil & gas international consortium for the development of visualization technology for geoscience and engineering applications in virtual environments. VRGeo has presented many significant contributions on the use of VR technology, especially in the area of collaborative work in virtual environments. Simon et al. [2005] presented a qualitative and quantitative study comparing usability and interaction performance with multi-viewpoint images, where a large-screen projection-based stereoscopic-display system is shared by a small group of people, each with their own viewpoint.

Another work was the VRGeo Demonstrator Project, for the interactive analysis of complex geological surfaces and volumes in an immersive VR system through co-located collaboration [Simon, 2005]. The authors present a new interaction paradigm that allows multiple users to share a virtual space in a conventional single-view stereoscopic projection-based display system, with each user manipulating the same interface and having a full first-person experience in the environment.

A combination of a collaborative problem-solving environment and VR visualization, which is not addressed by the aforementioned visualization systems, constitutes a strategic enabler for successful data exploration and knowledge dissemination among workers in engineering enterprises. VR visualization technologies enhance content knowledge within the engineering disciplines. In conjunction with collaboration, both provide valuable insights for better decision support with risk mitigation.

4 CEE Architecture

In order to achieve its goals, the CEE architecture is a composition of different computer-supported collaborative work technologies. The system is composed of a collaborative visualization environment (CVE) based on a virtual reality visualization (VRV) tool and a videoconference system (VCS); a scientific workflow environment (ScWfE) with grid computing infrastructure (GCI) support for executing large engineering simulations; and a project management environment (PME) responsible for controlling the overall execution of the project and keeping track of all the information and different artifacts generated during the whole lifecycle of the project.

The CEE allows users to solve their problems collaboratively, using predefined scientific workflows or assembling new ones as necessary. Each workflow comprises a sequence of simulations, usually ending with a collaborative visualization supported by a VRV tool.

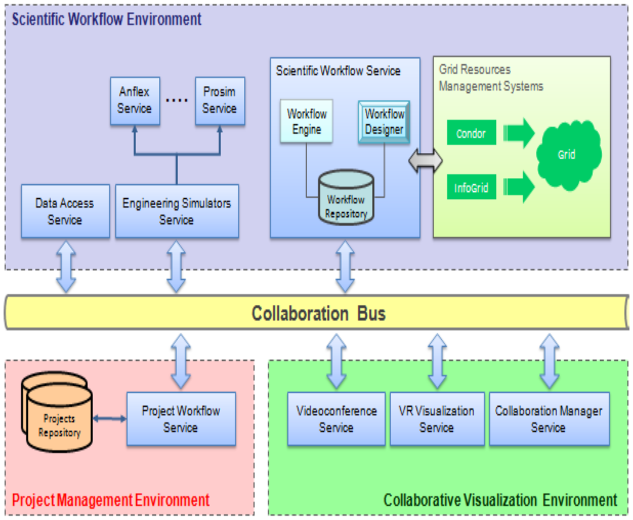

Figure 1: *CEE conceptual model.*

To achieve this, the CEE was devised as an extensible, flexible and system-independent platform, allowing a transparent flow of information among different levels, systems and models. The challenges for building an effective and useful solution can be scrutinized according to the following aspects:

1. **Collaborative work** – effective human-human interaction and communication for solving conflicts and enhancing group productivity should be supported;
2. **Virtual reality visualization (VRV)** – high performance and scalability are important aspects of virtual environment architectures intended to support the execution of large shared virtual worlds over long periods of time;
3. **Scientific workflow environment (ScWfE)** – challenges related to controlling the execution of engineering simula-

tions, such as interoperability and distributed execution as well as data provenance, should also be addressed;

4. **Project management environment (PME)** – the ability to track all of the documents and artifacts generated during the lifecycle of the project. Multiple and different visions of the ongoing project must be provided for users with different backgrounds.

The CEE conceptual model, presented in Figure 1, handles the above-mentioned challenges by creating specific services for them, constituting a service-oriented architecture (SOA) solution.

The CVE is responsible for managing user interaction. The VCS and the VRV services work closely coupled with the collaboration manager (CM) service to enable the creation of collaborative visualization sessions.

The ScWfE was created to help users build engineering workflows and seamlessly execute them in a GCI. For interoperability among applications, a common format for data exchange among engineering applications was developed.

The engineering simulators service provides web service interfaces [Lee et al. 2005] for the remote execution of engineering simulations. Those simulators are: Anflex [Mourelle et al. 1995], a finite-element riser analysis software, and Prosim, a coupled analysis software for the design of floating production systems.

4.1 Scientific Workflow

Ellis et al. [1999] implement workflow management systems (WfMSs) as tools to assist in the specification, modeling, and enactment of structured business processes within organizations. These systems are a special type of collaboration technology, which can be described as "organizationally aware groupware".

Although the above definitions make reference to "business processes", WfMSs are not only employed by business applications. Weske et al. [1998] identified that, in a scientific environment, scientists will typically specify their workflows themselves, while, in a business environment, a system administrator is commonly responsible for this task.

Scientific workflows often begin as research workflows and end up as production workflows. Early in their lifecycle, they require considerable human intervention and collaboration; later they begin to be executed more automatically. Thus, in the production mode, there is typically less room for collaboration at the scientific level, and the computations are more long-lived. During the research phase, scientific workflows need to be enacted and animated (fake enactment) far more intensively than business workflows. In this phase, which is more extensive than its counterpart in business workflows, the emphasis is on execution with a view to design, and thus naturally includes iterative execution. The corresponding activity can be understood as "business process engineering" (BPE). For this reason, the approaches for constructing, managing, and coordinating process models are useful also in scientific settings.

4.2 Support for Collaborative Work

Collaborative systems should allow multiple users not only to interact with shared objects but also to communicate and coordinate their actions. Collaboration may be seen as the combination of communication, coordination and cooperation [Ellis et al. 1991]. Communication is related to the exchange of messages and information among people. Coordination is related to the management of people, the interdependencies among their activities and the resources used. Cooperation is the production of common artifacts taking place in a shared space through the operations available to the group.

In our environment, support for collaborative work is provided by a ScWfMS, a VCS and a collaboration bus (CBus), which is a collaborative infrastructure for integrating the execution of engineering applications with our VRV component. This allows users to collaboratively view their results and optionally create virtual annotations, sharing knowledge about the engineering artifacts being viewed. An annotation, in our context, is any textual information that users want to add to their projects to enrich the content or just for documentation, having a private or public (shared) scope. Annotations can be associated to any artifact manipulated during a collaborative visualization session, which usually happens at the end of the execution of any sequence of engineering simulations (Figures 6 – 9).

An annotation may represent instructional information related to a sequence of operations that should be undertaken during an equipment maintenance intervention, for instance. It can also be any textual information used to highlight interesting or anomalous events observed in the simulation results. Examples of such events could be unexpected values for an engineering figure, violations of integrity, etc. Annotations can also have a more dynamic behavior, for instance representing the distance between different objects that should be monitored during a simulation.

Cooperation also occurs when assembling engineering workflows that will be used to orchestrate the execution of engineering applications, and also during the visualization of results, when users can collaborate to better understand the model. Users can also share persistent annotations about interesting facts, as previously discussed.

The most important scenarios for awareness support are:

1. **Event monitoring** – observing what is going on in the VRV, in all separate parts, and providing active notification to the right person, at the right time and in the selected subsystem;
2. **Workspace awareness** – providing control of collaborative interaction and changes in the user location;
3. **Mutual awareness** – allowing users see each other's identity and observe each other's actions;
4. **Group awareness** – facilitating the perception of groups of interest by connecting people who need to collaborate more intensely. Informal communication provided by a VCS enhances team awareness.

The CM is responsible for managing user participation in a collaborative session and for integrating the resources of VRV and VCS. Users can request the coordination role to the current coordinator, who can accept or reject the request, generating a visual feedback to the requestor. Upon the occurrence of a "change coordinator" event in a CEE collaborative session, all users are notified by the awareness mechanism. At any time, the user can disconnect from the session to do private work, and reconnect later. Then, the user's state is resynchronized with the state of the session, which is controlled by the CM service.

The CBus is a key component of the overall architecture and provides synchronous and asynchronous communication among the CEE components. It is a communication infrastructure based on the JMS Service Provider, the message-oriented middleware used for providing the public/subscribe and point-to-point paradigms, and the enterprise service bus.

The CEE awareness service provides appropriate actuators for events received from the CBus. It is responsible for signaling distributed events to the users participating in a collaborative session. On one side, all components trigger events to this CBus, and on the other side awareness components listen to the bus to gather information about what is happening in the system. When users leave a collaborative session or when there is a change in its state from offline to online and vice-versa, "update user" events are triggered in the CBus, and the CEE awareness mechanism sends messages to the VRV and the VCS services notifying the event. These services then signal those events in their user interfaces, making users aware of what happened.

4.3 VR Visualization Tool

3D CAD models show their potential in VR applications for diverse purposes, such as ergonomic studies, safety training, and visualization of physical simulations, project documentation and real-time operational data.

Environ [Raposo et al. 2009] was developed to facilitate the use of massive CAD models in VR applications. It is a system composed of a 3D environment for real-time visualization and plugins to import models from other applications, allowing users to view and interact with different types of 3D data, such as refineries, oil platforms, risers, pipelines and terrains. This tool is integrated into the complete system, offering resources for real-time 3D visualization and interaction with CAD models with enough realism and performance to be used for collaborative virtual prototyping, design review, change management, training, and visualization of simulations, among other activities (Figure 2).

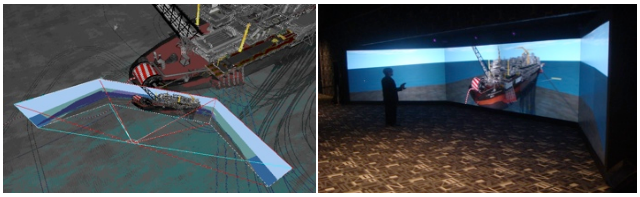

Figure 2: *Virtual representation of a cave and user interaction.*

The use of stereoscopy for immersive applications in engineering is essential. This is achieved through user head-tracking, multi-projection calculations and the determination of dynamic parameters of stereoscopy [Ware et al. 1998]. Head-tracking helps to determine the relative position of the user in the viewing screens. This position is the input to build suitable viewpoints. Figure 3 shows examples of different views from tracking the user's head.

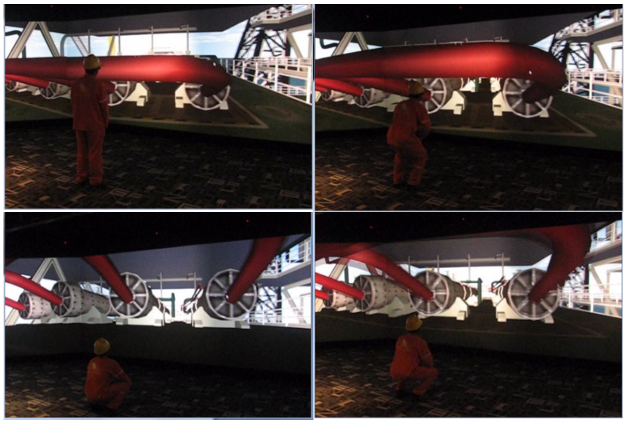

Figure 3: *Head-tracking with dynamic generation of viewpoints.*

Finally, in our scenario, the proper determination of the stereoscopy parameters is directly related to the navigation techniques of the immersive environment. For example, the operation "Go to" has as prerequisite the determination of the target object to start the navigation. Based on the size of this object, the representation is scaled and the stereoscopic parameters (eye distance and zero parallax distance) are dynamically calculated. A sequence of images illustrating scales in a cave is presented in Figure 4.

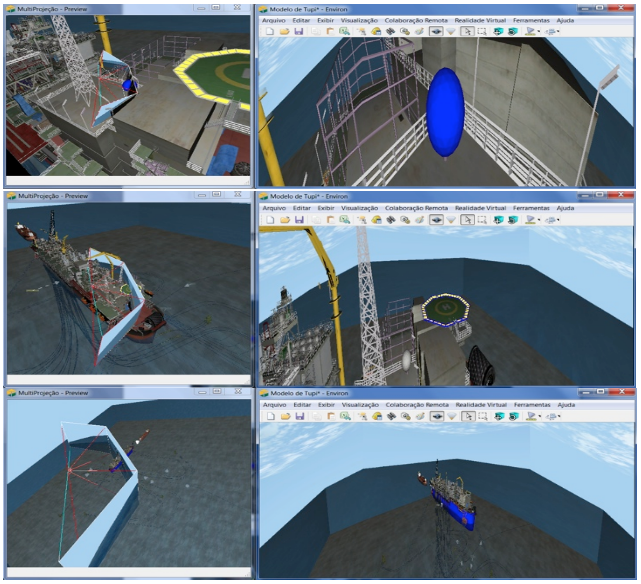

Figure 4: *Cave scales based on a target object.*

5 Application Scenarios

5.1 Collaborative Riser Analysis Workflow

An important step in deep-water oil exploitation is the elevation of the oil from depths over one thousand meters to the surface. Oil platforms use ascending pipes, called risers, which are tubular structures that convey oil and/or gas from the wellhead on the sea floor to the platform's separator system tanks [Senra et al. 2002A; Senra et al. 2002B]. To certificate the operation of the risers for their entire lifecycle (30 years or so), simulations of the stress applied to the riser system are conducted based on meteo-oceanographic data about wind, tide and water currents. Simulations are made under extreme environment conditions to test stress resistance. It is important to perform fatigue analysis studies to evaluate the most critical regions of the risers affected by cyclical stress in order to guarantee their integrity during their lifetime.

The analysis of risers requires the use of a suite of standalone programs. Since the analysis process is complex and handles a large amount of data files, this simulation is very hard to execute and manage manually. Furthermore, as the output files of one program are the input of another, it is necessary to make countless data manipulation and transformation operations using additional tools or programing new scripts to accomplish these tasks. Not only is this expensive in terms of time, it can also be error prone. In this context the use of a scientific workflow to represent and execute that sequence of simulations is an important feature of the system.

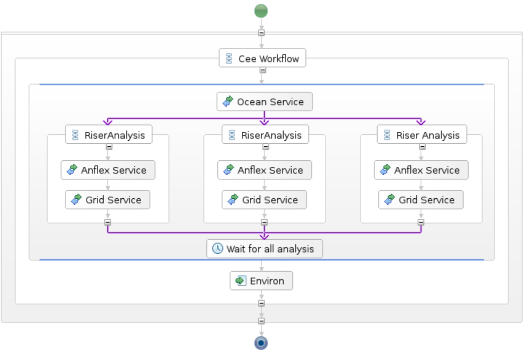

Figure 5: *Riser analysis workflow in the BPEL designer.*

An Anflex-based BPEL scientific workflow was defined for riser analysis. It is controlled by the BPEL engine, which automates the validation process and the certification of riser analysis. The workflow integrates the execution of the Ocean service, the Anflex service and the Grid Job service. In Figure 5 we show the final version of the riser analysis workflow in the BPEL designer.

The workflow starts with an Anflex base case, where the basic configuration is defined as production unit, riser geometry, soil bathymetry, etc. The Anflex service receives user input parameters from the BPEL designer and is responsible for creating different loading cases according to the different meteo-oceanographic conditions provided by the Ocean service. After that, the Grid Job service submits jobs for executing the simulation program on the available nodes of the computers grid.

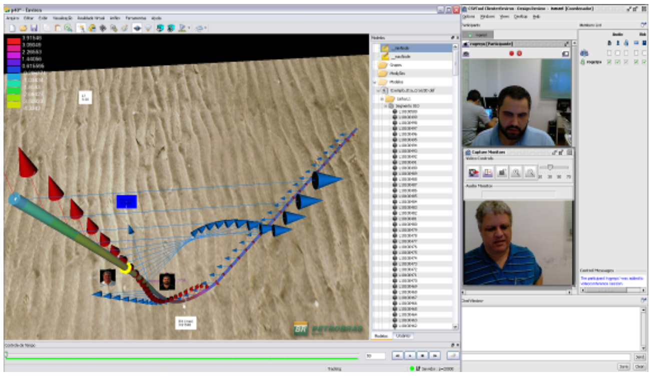

Figure 6: *Riser analysis (CAD + videoconference).*

In Figure 6, two 3D annotations were created automatically, showing the extreme points of a selected force or strength in the riser. The third annotation was created by the user to register an important observation made in this collaborative session.

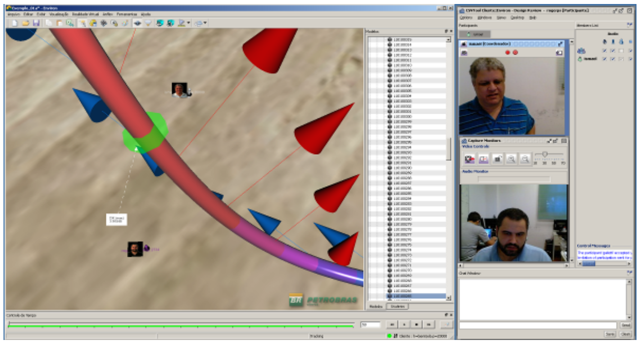

Figure 7: *Closer look at an element of the riser.*

It is also possible to playback the simulation, examine pipes, sea waves, ship movements, and select any element in a riser to examine it closely, especially those elements subjected to great stress, such as connecting joints and the touch down point. In Figure 7, the users are examining the behavior of a selected element in the riser (green ring), animated through the timeline bar.

At the end of the session both users will have all the information in their local copy. This information represents the state of the collaborative visualization session and can be stored in a file to recreate the scenario in the future.

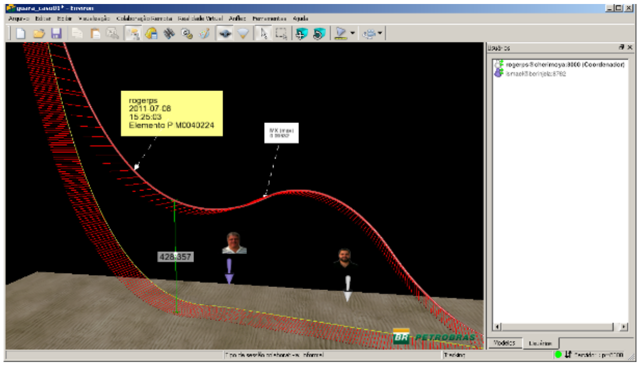

Figure 8: *Users in a collaborative visualization session.*

Figure 8 shows another collaborative visualization session, with a different set of risers. The picture shows a 3D annotation created automatically, and another annotation created by one of the users, making comments about an element in the upper riser.

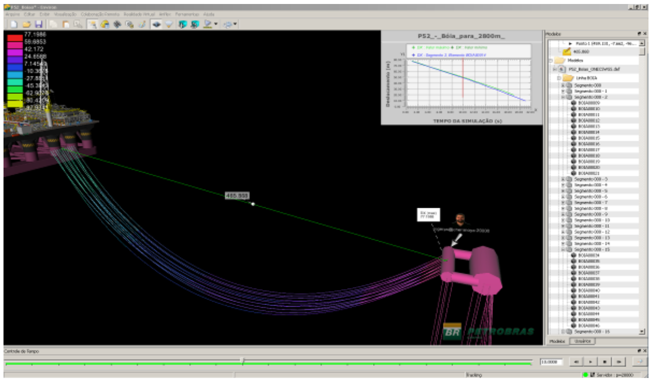

Figure 9: *Users monitoring the behavior of marine buoyant.*

As can be seen, in the users tab the awareness mechanism shows information about the status of the user (online, offline) and his/her role in the session (coordinator or participant). Figure 9 shows an engineering project where the users want to study the movement of a buoyant, used to reduce the stress on the risers. Using a buoyant, the movement of the platform hull can be decoupled from the movement of the riser system. The users are monitoring the distance between the buoyant and the platform, and are observing the behavior of some force on the risers.

5.2 Design Review Workflow

Design review is the process of checking the correctness and consistency of an engineering project while making the necessary adjustments. The design review workflow is a simplified version of the riser analysis workflow, where the workflow engine invokes the server to create a collaborative visualization session with the support of videoconference. In the session, users manipulate engineering objects, create annotations and do measurements.

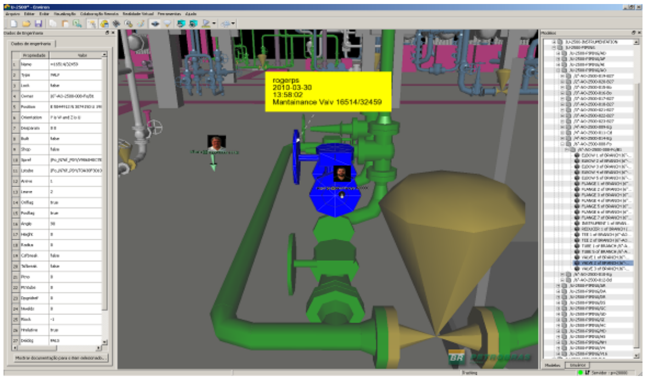

Figure 10: *Maintenance plan enriched with annotations.*

The ability to move, rotate and scale objects is important for various purposes, such as joining models, viewing hidden areas, planning the placement of new devices, and simulating a maintenance or intervention operation in a process plant. Moreover, integration with an engineering database from the CAD system is useful to create annotations emphasizing critical parts (Figure 10). Comments attached to objects can also be used as recommendations for project management.

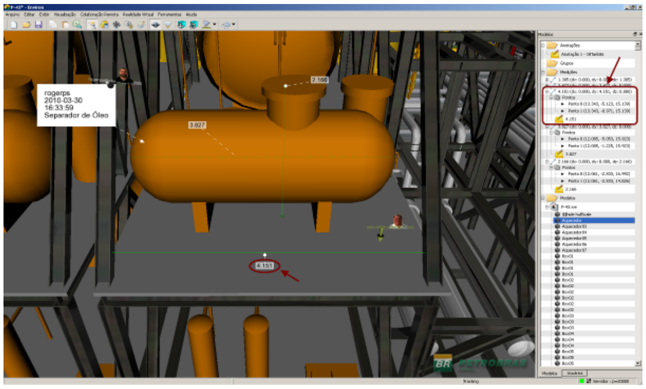

Figure 11: *3D measurements in a CAD model.*

Figure 11 shows a measurement taken for planning the movement of a large tank in a production unit. Users create annotations to guide the maintenance procedure and animate the entire operation.

5.3 Virtual Guided Tour

A user can follow the movements of another user, sharing the same view of the model. Figure 12 shows a collaborative visualization session, with both users following a 3D path passing through important points and creating annotations to mark events on the platform.

Figure 12: *Virtual guided tour.*

During VR collaboration, three types of sessions may exist in our system: Informal, Classroom and Lecture. For each type of session, the users have a status that is determined according to their role (coordinator or participant). The user in the coordinator state defines camera movements and ignores any camera movements from the other users (SendOnly), while all other participants can only receive commands and cannot send any camera movements (ReceiveOnly). In a Classroom collaborative session, it is possible to request the coordinator role; in a Lecture session this possibility is forbidden.

6 Conclusions

A collaborative environment was developed to optimize the execution of large-scale engineering projects, such as offshore engineering projects. With the integration of VR technologies into the workflows used by team members, we expect to improve the use of VR in offshore engineering projects, as illustrated in Figure 13. It is clear that better visualization resources and techniques improve the quality of engineering projects, but users, in general, do not want to spend much time preparing their content to be viewed in other systems, especially in complex immersive multi-projection environments. The CEE simplifies the daily job of engineers, from running simulations on a grid to visualizing their results in an immersive environment or a desktop afterwards. A specialized web interface was created where users can start immersive or desktop collaborative sessions to accomplish their job.

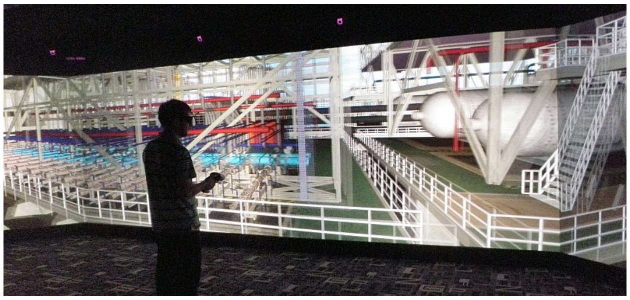

Figure 13: *User in a cave during VR Collaboration.*

From the offshore engineering point of view, the creation of customized scientific workflows to be used by the users during the project lifecycle in a structured and integrated way, constituting an effective collaborative problem-solving environment, is an important contribution.

In the future, it is estimated that many other organizations are going to start to use scientific workflows, which will become a common solution in highly complex enterprises where several areas must be integrated and synchronized. Although this work is focused on a solution for offshore engineering projects, we believe that our system could also be used in other areas.

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